Monitoring ground-dwelling mammals, Eastern Bristlebird and Ground Parrot at Vincentia on the south coast of New South Wales

Garry Daly
PO Box 3109 North Nowra NSW 2541.
gaiaresearch@shoalhaven.net.au

ABSTRACT

Fauna surveys were conducted near the coastal village of Vincentia on the south coast of New South Wales from 2000 to 2014 in response to a proposal to extend a golf course. The surveys consisted of trapping ground-dwelling mammals along six, 200 m long transects and targeted surveys for the Eastern Bristlebird *Dasyornis brachypterus* and Ground Parrot *Pezoporus wallicus*. Eight native species of ground-dwelling mammal were trapped including the White-footed Dunnart *Sminthopsis leucopus,* Eastern Chestnut Mouse *Pseudomys gracilicaudatus* and Eastern Pygmy Possum *Cercartetus nanus,* species currently listed on the *Threatened Species Conservation Act (1995)* and the New Holland Mouse *Pseudomys novaehollandiae* listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act (1999).* The most abundant mammals trapped were the Bush Rat *Rattus fuscipes* and the Brown Antechinus *A. stuartii* accounting for 67% and 14% of all Elliott trap captures, respectively. The survey provided the first live specimens of Eastern Chestnut Mouse in the region, a range extension of some 270 km south of the previous record. The total number of Bush Rats, Swamp Rats and House Mice trapped in Elliott traps varied significantly over the monitoring period and between different transects. Mean captures per night of Bush Rat and Swamp Rat, increased over the period of each survey. The site supports a high density of Eastern Bristlebird as evidenced by the number of calling birds and animals trapped. Two Ground Parrots were detected between 2000 and 2005, but not thereafter. Disturbance, particularly fire, may be important in determining the presence of Ground Parrots and White-footed Dunnart at this site.

Key words: Jervis Bay, ground mammals, eastern bristlebird, ground parrot, impacts of clearing, fire.

https://doi.org/10.7882/AZ.2017.003

Introduction

In the year 2000 Vincentia Golf Club proposed to extend the existing golf course by clearing 2 ha of native vegetation. Fauna surveys were conducted to support the development application. Clearing of bush for the development was progressive during the assessment and has been ongoing. Habitat fragmentation, caused by human modification of ecosystems, is a major driver of biodiversity loss (Fahrig, 2003; Kingsford *et al.,* 2009; Lindenmayer and Fischer, 2006). Studies on pyric succession of small mammals in coastal heathlands of New South Wales (NSW) have led to theories on species replacement sequences (Fox and McKay 1981) and the study site had experienced fire. The monitoring program presented an opportunity to assess the relative abundance and species richness of ground-dwelling mammals, Eastern Bristlebird *Dasyornis brachypterus* and Ground Parrot *Pezoporus wallicus* over 12 consecutive years (2003-2014) in conjunction with the progressive loss of habitat and succession post-fire. The impacts of fire, loss of habitat and variation in rainfall on the populations are discussed. Comments are provided on distribution and habitat preference of each species to give a regional perspective.

Methods

Study area

The study site (80-100 m AHD) is located on the south coast of NSW, some 200 km south of Sydney 35° 05' latitude and 150° 41' longitude (Figure 1) within the catchment of Jervis Bay. The total area related to this study covered approximately 13 ha of native vegetation of which two hectares was progressively removed during the survey. The site is adjacent to a 230 ha portion of Jervis Bay National Park (NP), which adjoins Booderee NP (6300 ha). The area has a temperate maritime climate with an average rainfall of 1150 mm year spread relatively evenly over the year. Average minimum and maximum air temperatures are 18 and 24° C for January (summer) and 9.5 and 15° C for July (winter) (Bureau of Meteorology 2007).

Geology and soils

Vincentia is located on Bherwerre peninsula, which forms the southern isthmus of Jervis Bay. The isthmus is underlain with Permian sandstones, siltstones and conglomerates of marine origin (Snapper Point Formation) within the Sydney Basin (Douglas 1973). The soil is shallow and sandy being derived from sandstone on a plateau that

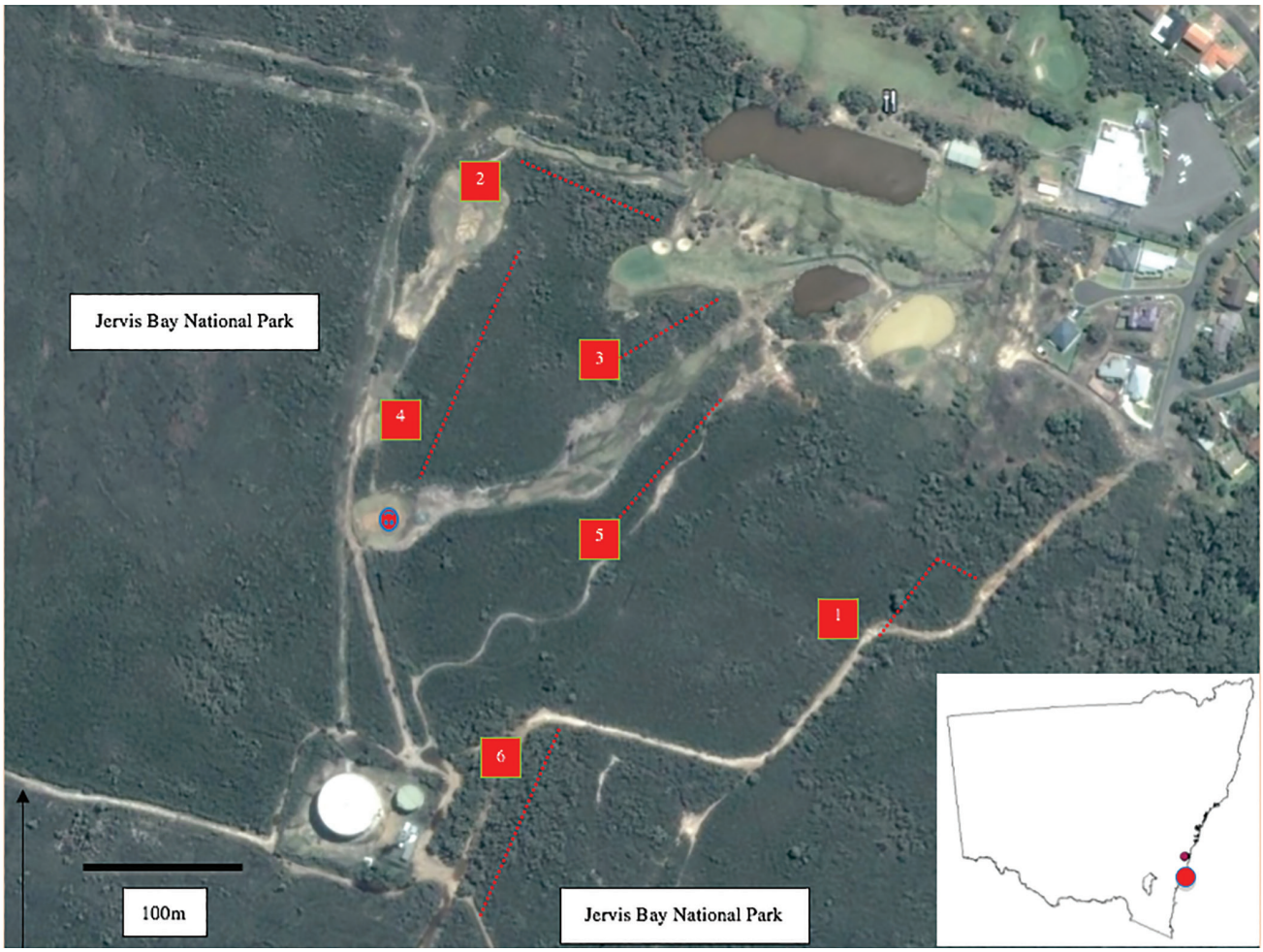

Figure 1. Detail of study area and approximate locations of trapping transects. Red hatches lines represent approximate location of the six mammal trapping transects, the blue/red circle represent the approximate location of Ground Parrot dusk census

extends from the survey site to the adjoining national parks. Rock outcrops and loose boulders are present in a limited portion of the study site.

Description of the broad vegetation associations

The vegetation on the site is diverse with 170 species located in sedgeland (c. 4 ha), heath (c. 7 ha) and woodland (c. 2 ha) (Gaia Research 2001). Sedgeland occurs in the areas with the shallowest soils and has a high exposure of direct sunlight. Typical species include Round-headed Bristle-rush *Chorizandra sphaerocephala,* Slender Twine-rush *Leptocarpus tenax* and Spreading Rope-rush *Empodisma minus*. Sedgeland attained a height of about one metre.

The heathland is aligned with the communities Hairpin Banksia - Slender Tea-tree heath on coastal sandstone plateaux and She-oak – Hairpin Banksia heathland on sandstone headland (Biometric ID 557 and 618, OEH 2013). Heathland attained a height of 3 m and common species included Dagger Hakea *Hakea teretifolia* and Heath-leaved Banksia *Banksia ericifolia.* The rare (ROTAP) Epacris-leaved Tea-tree *Leptospermum epacridoideum* was common at several locations where heathland abutted woodland.

The woodland is Red Bloodwood - Scribbly Gum heathy woodland on sandstone plateaus (Biometric ID 595, OEH 2013). The main trees were Scribbly Gum *Eucalyptus sclerophylla* and Red Bloodwood *Corymbia gummifera* with the occasional Budawang Ash *E. dendromorpha,* Silvertop Ash *E. sieberi,* Green Wattle *Acacia irrorata*, Two-vein Hickory *Acacia binervata* and Small She-oak *Allocasuarina distyla.* The species-rich shrub understorey contained plants typically found on the sandstone derived soils of Bherwerre Peninsula including Heath-leaved Banksia, *Hakea* spp., *Leptospermum* spp., and Conesticks *Petrophile sessilis.* Woodland attained a height of 4 to 5 m.

Survey methods for the vegetation

Flora surveys involved the establishment of six, 20 m x 20 m, quadrats to monitor changes in species composition, density and height from 2003 to 2015. All quadrats ran on a north south axis. The north-east corner of each was marked by a star picket that was double flagged with pink tape to facilitate relocation. Cover scores were made at three height ranges and two images were taken of each quadrat annually (Appendix 1). Plant identifications for species at each quadrat were made according to nomenclature used in Harden (1993).

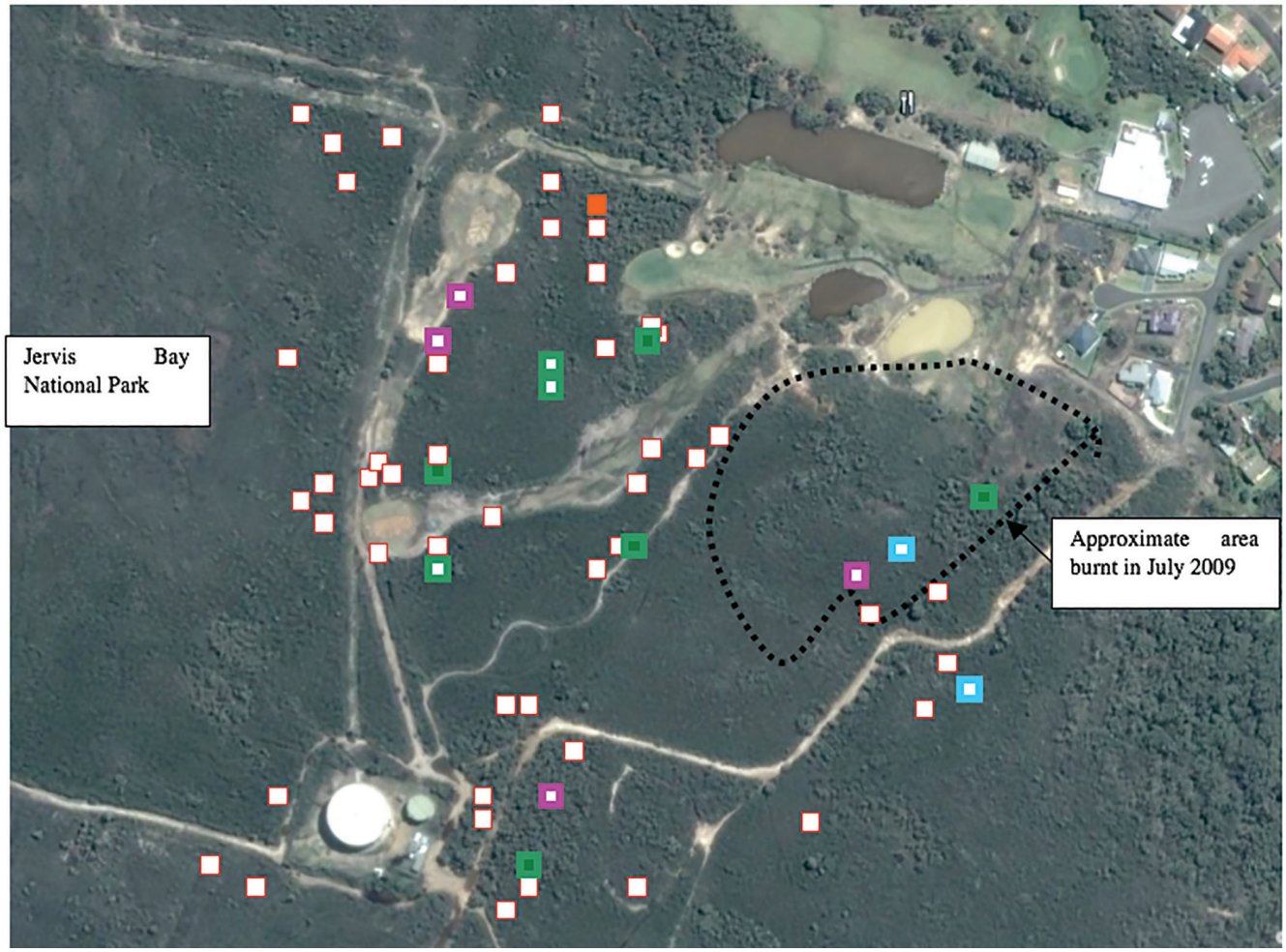

Figure 2. Detail of Subject Site indicating location of various holes, location of threatened fauna from September 2001-2014. Notes: Red boxes represent approximate locations of Eastern Bristlebird prior to 2014. Green filled boxes are Eastern Bristlebird locations where birds were trapped. Blue boxes represents approximate location of White-footed Dunnart. Purple box represent approximate locations of Eastern Chestnut Mouse. Green box represents approximate locations of Ground Parrot and orange filled box represents the approximate location of the Eastern Pygmy Possum The south-eastern record of the White-footed Dunnart is from Daly (1994)

Disturbance to the site

Adjacent to the study site approximately 7 ha of native vegetation had been either removed or modified by quarrying, the construction of roads, dams and easements. The quarry operated from 1976 – 1979 and two small dams were constructed at that time (Figure 1). A third larger dam was constructed to irrigate the course in 1969 and was enlarged in 1979.

The entire site was burnt was 1994 (R. Baldwin pers. comm.) and about 1.9 ha in July 2009 (Figure 2). During the course of the survey an additional five holes were constructed, amounting to the progressive loss of about 2 ha of bush. Unsealed tracks some 3-10 m wide break the native vegetation cover in some locations between the site and Jervis Bay NP. During the survey clearing was undertaken progressively for the development with habitat removal and disturbance being pronounced in select areas (trapping transects 2, 3 and 4). Exotic animals were a disturbance factor and Red Fox *Vulpes vulpes* and Rabbit *Oryctolagus cuniculus* were present.

Survey methods for ground dwelling mammals

The methods used for the surveys were based on those devised by the NPWS southern Comprehensive Regional Assessment (CRA) unit (NPWS 1999). Ten size A Elliott (Elliott Scientific Equipment, Upwey, Victoria) traps (0.1 x 0.1 x 0.3 m) were set along six, 200 m lines (herein termed transects) at regular intervals for ten consecutive days in the summer (Figure 1) of 2000 then for four consecutive days each spring from 2003-2014. Since the species of mammal studied breed during regular seasons the bulk of the surveys were timed to reduce variations caused by seasonal demographics. In the case of the Brown Antechinus *A. stuartii*, the surveys occurred at a time when there were few males present because of their annual "die off". Animals were not marked to identify recaptures.

Transects were separated by a minimum of 10 m and located within 10 m of access roads/clearings. Transects were located across the site to sample a range of vegetation communities/habitat types (Figure 1). Monitoring of the vegetation occurred annually and a density rating was

given for the Heath-leaved Banksia, the most abundant shrub on the site. The locations of the transects were determined from a global positioning device (Garmin 400t) (Table1) and relocated each year from flagging tape.

Prior to the surveys traps were sprayed with high pressure water, then scrubbed and resprayed, then rinsed in clean water and finally sun dried to reduce the risk of contamination of odours. The release mechanism of the Elliott traps was adjusted so they triggered with less force. This modification was considered necessary to enhance the capture of small mammals, such as Dunnarts *Sminthopsis* spp. and New Holland Mice *Pseudomys novaehollandiae*.

Traps were set on the ground (scuffed by foot to make the trap flush with the ground) and baited with a mixture of peanut butter and rolled oats. The traps were placed under bushes or other vegetation to protect captured animals from the elements and where possible at right angles and opening onto runways. Leaves were placed in and on top of the traps to provide insulation and material for animals to use as bedding. Soiled traps were replaced with clean ones as it was considered that used traps smell and may bias results or may not function correctly because the movement of the spring mechanism may be impeded by bait/faecal material. Flagging tape marked the location of traps and the scuff marks often indicated the specific location where they had been previously set.

Two medium sized (0.2 x 0.2 x 0.55 m) cage traps were set along each transect. One was located at the beginning and the other midway along each trap line in locations flattened to ensure the traps were flush with the ground and stable. The cage traps were baited with a mixture of sardines (in oil), peanut butter and rolled oats and set for the same period as the Elliott traps. Cage traps were rebaited on day three or when animals had been caught. Traps were checked within two hours of sunrise and, apart from House Mice *Mus musculus* (euthanased as per the requirements of my scientific and ethics licences), captured animals were generally released after identification.

Surveys method for Eastern Bristlebird and Ground Parrot

Surveys for Eastern Bristlebird occurred annually in the spring and summer of 2000, then in spring from 2003-2014 by way of aural census and direct observations. Population size of Eastern Bristlebird was estimated by morning aural surveys along transects (Baker 1998). The population was indexed by the cumulative maximum total achieved for a single census (calling and sighted birds plus any trapped). Approximately two hours of early morning censuses were conducted over 1200 m for five consecutive days annually along the mammal trapping transects. Occasional birds were caught in cage and Elliott traps. The locations of birds detected were recorded in order to map their distribution across the site.

Two dusk surveys were conducted for calling Ground Parrot annually each spring. The surveys were conducted at a set location on the western edge of the site (Figure 1). The surveys were conducted for approximately 45 min, during periods when it was relatively calm as it was considered these conditions maximised detection of calling birds. The locations of Eastern Bristlebirds detected during the Ground Parrot dusk surveys were also recorded.

Analysis of mammal transect data

For each 200 m transect the total number of mammal species (species richness) trapped and the total number of each species (abundance) were tallied for each year for the period 2000 to 2014 (Tables 2 and 3). In the initial survey, trapping was conducted prior to clearing for 10 consecutive days (Gaia Research 2001) and to standardise these data I used the results from the first four days. Data from the initial survey were not used for statistical analysis as there was a gap of three years until the subsequent survey and the initial survey was conducted during summer as opposed to spring. Standardising seasons was considered important to reduce biases from generational recruitment.

Since cage traps captured Bush Rats *Rattus fuscipes* and Swamp Rats *R. lutreolus*, but not smaller mammals, tallies of these species were made for Elliott traps and total captures

Table 1. Start locations of Elliott and cage trapping transects and vegetation community

Notes: Co-ordinates in GDA 94 Datum Zone 56. Cover abundance of *Banksia ericifolia* (transects 2-5) and *B. oblongifolia* (transect 6) scale modified from Braun-Blanquet (rating of 1-6 with six being 76-100% cover). No cover rating given for transect 1 as it was burnt and also partially cleared.

Transect	Easting	Northing	Vegetation community	Cover
1	288625	6115226	Sedgeland and woodland	Not applicable
2	288452	6115477	Woodland	2
3	288507	6115413	Woodland and heathland	2
4	288333	6115307	Sedgeland and heathland	2
5	288485	6115312	Heathland (tall)	4
6	288452	6115124	Woodland	1

Table 2. Total number of various species caught in Elliott traps from 2000-14

Note: Percent success is total captures divided by total trap nights. House Mice euthanased post capture and no recaptures. Eastern Bristlebird aural are the results obtained from aural surveys and represent minimum birds detected (seen and/or heard) on and adjacent to the transects

Species	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
White-footed Dunnart	1	0	0	0	0	0	0	1	0	0	0	0	0
Brown Antechinus	3	8	15	15	15	5	8	6	3	9	3	9	16
Eastern Pygmy Possum	0	0	0	0	0	0	0	0	0	0	1	0	0
Swamp Rat	12	2	1	4	7	2	8	3	4	5	2	1	0
Bush Rat	27	15	23	35	24	41	53	34	55	66	77	50	39
House Mouse	1	7	11	20	12	3	6	8	6	5	6	0	0
Eastern Chestnut Mouse	0	0	0	0	1	0	0	1	2	3	0	0	0
New-holland Mouse	0	0	0	0	0	0	0	1	0	0	0	0	0
Long-nosed Bandicoot	0	0	0	0	0	1	1	1	1	0	0	0	0
Eastern Bristlebird	0	2	3	2	1	2	4	3	0	2	1	2	2
Eastern Whipbird	0	0	0	0	0	0	0	0	0	0	1	0	0
White-browed Scrubwren	0	0	0	0	0	0	0	0	1	1	0	0	0
Superb Fairy Wren	0	0	0	0	0	0	0	0	0	1	0	0	0
Scaly Foot	0	0	0	0	0	0	0	1	0	0	0	0	0
Jacky Dragon	0	0	0	0	0	0	0	1	0	1	0	0	0
Percent Success	19	14	22	32	25	23	33	24	30	39	37	26	24
Total species mammals	5	4	4	4	5	4	5	8	6	5	5	3	2
Eastern Bristlebird aural	6	4	6	8	10	10	6	6	5	8	6	6	6
Ground Parrot aural	2	3	2	2	0	0	0	0	0	0	0	0	0

Table 3. Total number of various species caught in cage traps from 2000-14

Note: Percent success is total captures divided by total trap nights

Species	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Long-nosed Bandicoot	0	2	6	7	2	4	2	1	4	0	2	1	0
Swamp Rat	3	1	0	0	4	1	0	0	0	5	0	0	0
Bush Rat	0	9	3	8	6	11	18	4	12	9	26	10	9
Eastern Chestnut Mouse	0	0	0	0	0	0	0	0	1	0	0	0	0
White-browed Scrubwren	0	0	0	0	0	0	0	0	2	1	0	0	0
Painted Button-quail	1	0	0	0	0	0	0	0	0	0	0	0	0
Eastern Bristlebird	0	0	0	1	2	0	1	0	2	2	1	1	4
Eastern Whipbird	0	0	0	0	0	0	0	0	1	0	0	0	0
Pied Currawong	0	0	0	0	0	0	0	0	0	0	1	0	0
Eastern Bluetongue Skink	0	0	0	0	0	0	0	0	0	1	0	0	0
Jacky Dragon	0	0	0	0	0	0	0	0	0	1	0	0	0
Percent Success	3	10	7.5	13	17.5	33	44	5	44	40	62.5	25	19
Total species mammals	1	3	2	2	3	3	2	2	3	2	2	2	1
Total mammals	3	12	9	15	12	16	20	5	17	14	28	11	9

(Elliott plus cage traps) so that these figures could be considered separately. This allowed a statistical analysis to test the hypothesis that changes in vegetation density and rainfall impacted on the capture rate of the most abundant species (Bush Rat, Swamp Rat, Brown Antechinus and House Mouse *Mus musculus*). A non parametric Friedman test was used to test for differences in capture rate.

RESULTS

Small Mammals

Elliott trapping

Over 13 years of trapping a total of 805 small mammals were caught of nine species in a total of 3120 Elliott trap nights (Table 2). The overall capture rate for Elliott traps was 26 % and the trap rate per 100 trap nights for each species is given in Table 4. The most common small mammals captured were the Bush Rat, Brown Antechinus and House Mouse, which accounted for 67 %, 14 % and 10 % of all captures, respectively. Less commonly captured species included the Swamp Rat, White-footed Dunnart *Sminthopsis leucopus*, Eastern Chestnut Mice *Pseudomys gracilicaudatus*, New-holland Mouse *P. novaehollandiae*, Eastern Pygmy Possum *Cercartetus nanus* and Long-nosed Bandicoot *Perameles nasuta* (juveniles and subadults).

Cage trapping

Over the surveys a total of 171 mammals were trapped covering four species over 624 cage trap nights (Table 3). The capture rate for cage traps was 26 %. The most common mammals were the Bush Rat, Long-nosed Bandicoot and Swamp Rat accounting for 73%, 18% and 8% of captures, respectively.

The highest density of Bush Rats and total captures was found along the transect (number 5) that supported a tall (4m), dense heath dominated by Heath Banksia. Long-nosed Bandicoot were trapped in cage traps in most years. The trap rate for bandicoots was not sufficient to conduct statistical analysis, but ranged from 0-7 captures. The total number of mammals captured (cage plus Elliott traps) on various transects over the four days is given in Table 5.

General Results

Mammal species richness over the 12 years ranged from 0-6 per transect/per year (Table 6). In the year 2004 the highest species richness was recorded (Elliott and cage traps) with four species being trapped on each transect. The highest average species richness was found in heathland/sedgeland with rock outcrops and the lowest in woodland without rock outcrops. Over the last two years of trapping there was a decline in species diversity. There was an increase in the total mammals trapped with each successive day (Table 5) but this result was not statistically significant.

The area experienced below average rainfall for a decade prior to 2010. During 2011 - 2013 rainfall for Nowra was about average but more episodic leading to a progressive drying of the site. This may have resulted in a decline in Swamp Rats and increase in Bush Rats trapped.

Analysis of records of common mammal species

Temporal changes in abundance

The common species of small mammals exhibited differing patterns of capture across the monitoring period. Mean yearly capture rates for these species is displayed in Figure 3. The total number of Bush Rats trapped

Table 4. Elliott trap capture totals and time until the capture of various species

Note: total trap nights = 3120 (= no. traps x no. transects x no. nights).

Trap nights until first capture was calculated by adding the number of trap nights completed prior to the date of capture, plus the number of traps in the relevant transect checked before the trap that captured the animal. Traps were always checked in the same sequence and trap 5 was taken as the mid point for the capture.

Species	Number of times captured in this study	Capture Rate (captures per 100 trap nights)	Trap nights until first capture*
White-footed Dunnart	2	0.06	55
Brown Antechinus	115	3.69	15
Eastern Pygmy Possum	1	0.03	2465
Swamp Rat	51	1.63	75
Bush Rat	539	17.27	5
House Mouse	85	2.72	95
Eastern Chestnut Mouse	7	0.22	1065
New-holland Mouse	1	0.03	1825
Long-nosed Bandicoot	4	0.13	5
Total captures	**805**		
Eastern Bristlebird	**24**	**0.75**	

Table 5. Total number of mammals captured on various transects over the four days

Note: Data from 2003-2014 trapping sessions

Site	Day 1	Day 2	Day 3	Day 4	Total
1	19	17	24	19	**79**
2	20	27	26	26	**99**
3	23	23	23	26	**95**
4	40	40	41	37	**158**
5	28	56	54	63	**201**
6	28	28	35	41	**132**
	158	**191**	**203**	**212**	

(Elliott plus cage traps) per year varied significantly over the monitoring period (Friedman's non parametric test, Q=75.3, 11d.f., P<0.0001). Numbers steadily rose from 2003 to a peak in 2012 and a subsequent decline over the last two years of monitoring.

The total number of Swamp Rats trapped in Elliott and cage traps also varied significantly between years (Friedman's non parametric test, Q=32.3, 11d.f, P<0.001) with the highest captures in 2006 and 2011. The total number of Brown Antechinus trapped in Elliott traps was not significantly different between years (Friedman's non parametric test, Q=17.3, 11d.f., P=0.100).

The total number of House Mice trapped in Elliott traps per year varied significantly between years (Friedman's non parametric test, Q=39.2, 11 d.f., P=0.001). Captures of this species peaked two years after the commencement of monitoring then slowly declined with no captures in the last two years of survey.

Differences in Capture Between Transects

The most common species of small mammals exhibited differing patterns with regard to capture across transects (Figure 4). The number of Bush Rats trapped in Elliott traps was significantly different between transects (Kruskal-Wallis non parametric test, H=67.0, 5d.f., P<0.0001) with the highest captures at transect 5 followed by transects 4 and 6. Transect 5 had the densest shrub cover (Table 1, Appendix 1) with stands of Heath Banksia attaining 4m.

The total number of Swamp Rats trapped in Elliott and cage traps also varied significantly across transects (Kruskal-Wallis non parametric test, H=23.2, 5d.f., P =0.0003). The highest capture was at transect 4 and the lowest captures at transect 1.

Table 6. Total mammal species diversity per transect from 2003-14

Note: includes mammals trapped in both Elliott and cage traps

Transect	2003	2004	2005	2006	2007	2008	2009	2010	2011	2112	2013	2014
1	2	3	4	5	3	4	2	0	1	2	2	2
2	3	1	4	2	3	3	2	2	2	4	3	2
3	3	4	4	1	2	5	1	3	2	3	2	1
4	3	3	4	2	5	4	6	2	3	2	2	2
5	2	4	4	2	2	1	2	5	2	2	1	5
6	2	2	4	3	2	3	2	2	2	2	1	2

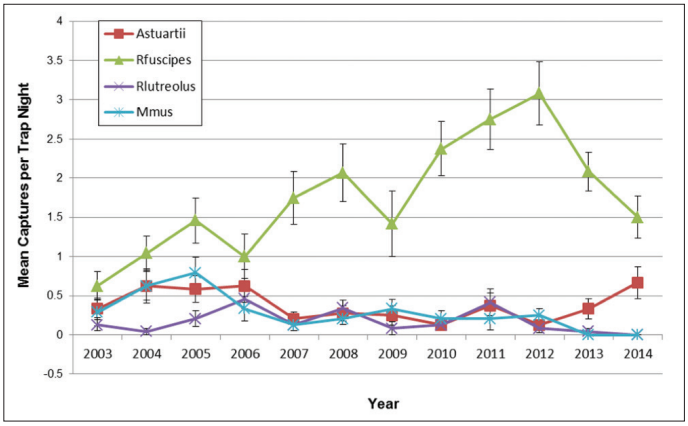

Figure 3. Mean number of common mammal species caught in Elliott traps during annual surveys between 2003-2014

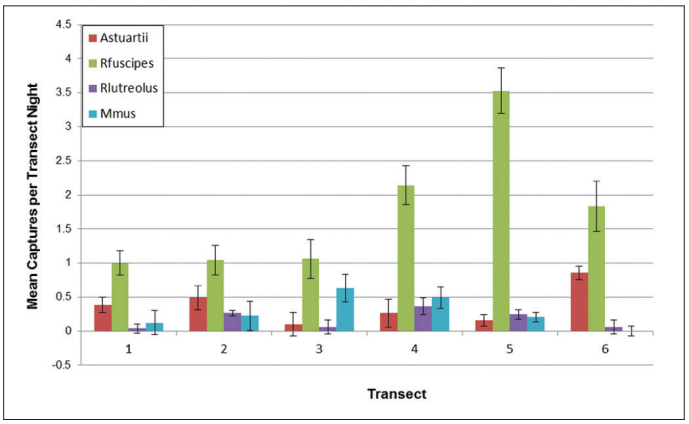

Figure 4. Mean number of common mammal species caught in Elliott traps per transect per night for the period 2003-2014.

Note: Error bars denote one standard deviation or the mean.

The total number of Brown Antechinus trapped in Elliott traps varied significantly between transects (Kruskal-Wallis non parametric test, H=33.6, 5d.f., P <0.0001). The highest capture was at transect 6 and the lowest captures at transect 3. The vast majority of animals trapped were females with pouched young. No independent juveniles were trapped and the few males were moribund.

The number of House Mice trapped in Elliott traps was also significantly different between transects (Kruskal-Wallis non parametric test, H=38.0, 5d.f., P<0.0001). The highest captures of this species were at transects 3 and 4, while the lowest captures was at transect 6.

Rare and /or threatened mammal species

Three species currently listed under the *TSC Act (1995)* were caught. They were the White-footed Dunnart, Eastern Chestnut Mouse and Eastern Pygmy Possum. In addition, the regionally rare and Nationally threatened New-holland Mouse was captured.

Over the 13 years (4 days per year) of trapping there were two captures of White-footed Dunnart, one Eastern Pygmy Possum, one New-holland Mouse and 8 captures of Eastern Chestnut Mouse (seven in Elliott traps and one in a cage trap). This equates to a capture rate per 100 trap nights of 0.06 for White-footed Dunnart, 0.03 capture rate for Eastern Pygmy Possum and New-holland Mouse and 0.22 for Eastern Chestnut Mice (Table 4). A large effort was required over a long period to detect these species. The capture rates suggest these species occur in low abundance and/or are reluctant to enter traps. The time until first capture of each species is given in Table 4.

One White-footed Dunnart was found in an area that had been burnt in 2009 and one animal was trapped near this site in 1994 (Daly 1994). The Eastern Pygmy Possum, New-holland Mouse and Eastern Chestnut Mice were found in an area of woodland/heath that had not been burnt since 1994 and contained loose rocks and a species diverse shrublayer. The Eastern Chestnut Mouse was trapped in 2006 then from 2009-11 only in bush that had not been burnt for 12-17 years.

Eastern Bristlebird and Ground Parrot

The Eastern Bristlebird was highly associated with heath with foliage cover greater than 60%. The locations where Eastern Bristlebird were found was consistent over the monitoring period, with birds frequently detected (calling) from Jervis Bay NP west of transect 1. Birds were caught in both Elliott and cage traps on transects 3, 4, 5 and 6 (Figure 2). The capture rate was 0.74 per 100 Elliott trap nights. Based on calls (duetting) and behaviour, birds probably nested near transects 4 and 5. Aural surveys detected two to three pairs of Eastern Bristlebird at consistent locations over the survey giving a conservative density of about one bird per 0.5 ha. In addition other birds were heard calling from bushland in the adjacent National Park (Figure 2). On several occasions a bird was trapped while other birds called nearby suggesting additional birds (fledglings or dispersing birds) were within a pair's territory. Birds were observed to move over the semi-cleared easements and narrow unsealed roads.

Prior to the 2009 fire, a pair of Eastern Bristlebird was recorded annually duetting from the area covered by transect number 1. No Eastern Bristlebirds were trapped or heard calling from this site post-fire until 2013. Eastern Bristlebirds were observed to forage for insects on the edge of a golf green that had recently been fertilised. The approximate locations of birds detected by all methods are given in Figure 2.

Ground Parrots were heard calling or flushed while checking traps between 2001 and 2005 in areas that supported sedgeland and dense heath. Two birds (possibly a pair) were regularly heard calling during these years with a third detected in 2003 (Table 2). The locations where these birds were found are given in Figure 2.

Changes in Vegetation

There was no marked change in species composition at the three height ranges. However, the cover scores did change over time with a decrease in the lower two height ranges and an increase in the cover of the tallest species as the vegetation grew taller (Appendix 1).

Discussion

Mammal species diversity and density

The heath that grows on the Vincentia sandstone plateau supports eight native and one exotic species of ground-dwelling mammal. This represents a higher tally than that recorded in other bushland areas around Jervis Bay and the broader Shoalhaven (Table 7), a result partially reflective of the greater survey effort undertaken during this survey. The absence of disturbance (fire and clearing) over an extended period (6 to 24 years without fire) may partially account for the decline in species diversity over the last two years, but other factors such as rainfall patterns may be responsible.

The variation in rainfall may explain the increase in Bush Rat and decline in Swamp Rat as the overall drying caused from below average rainfall and episodic dumps may have favoured the Bush Rat. Apart from a change in rainfall patterns there may be a range of factors that have influenced the number of small mammals trapped.

The proposed pyric successional sequence of small mammals (Fox and McKay 1981) was not observed. Factors that may have contributed to my results include the post-burn regeneration that occurred before the study was initiated, additional disturbance caused by clearing and predation by Red Fox and competition with feral Rabbits. General trends were a pulse in House Mice post-disturbance (a result of clearing), a pulse in Eastern Chestnut Mouse over several

Table 7. Trapping effort at various locations in the Jervis Bay region and the small mammals caught

Note: Ea = Elliott traps – A size, Eb = Elliott traps – B size, and C = cage traps, all Dunnarts considered by author to be *S. leucopus*.

Report	Location	Search Effort Trap nights	No sp. native ground mammals	TSC Act listed species
Coyne *et al*. (1979)	Beecroft Peninsula, Jervis Bay	96 (Ea), 48 (Eb), 48 (C)	2	None
Braithwaite *et al*. (1988)	Jervis Bay – Currambene State Forest and Beecroft Peninsula	4065(E), 600(C)	4	White-footed Dunnart
Caughley (1993)	Booderee NP, Jervis Bay	Not given	2	None
Andrews, Neil (1993)	Heritage Estates, Jervis Bay	300 (E)	3	None
Daly (1994)	Vincentia Golf Course (Lively St)	100 (Ea)	3	White-footed Dunnart
AES (1995)	Heritage Estates, Jervis Bay	150 (E)	Not given	None
Daly & Leonard (1996)	Jervis Bay – Long Bow Point	500 (Ea)	2	None
Meek (unpub. data)	Jervis Bay, Booderee NP	620	2	None
Daly *et al*. (1998)	Cudmirrah and Conjola NP	330 (Ea), 66(C)	5	White-footed Dunnart
Kevin Mills (1998a)	Bay and Basin Leisure Centre, Jervis Bay	100 (E)	2	None
Kevin Mills (1998b)	Bay and Basin Leisure Centre, Jervis Bay	120 (C)	3	None
Murphy (1998)	Seven Mile Beach NP	810 (Ea) + 30 (Eb) 12(C)	3	None
Capararo & Murphy (1996)	Jervis Bay NP	1200 (Ea), 240(Eb), 120 (C)	2	None
Gaia Research (1999)	Jervis Bay NR	1200 (Ea), 240(Eb), 120 (C)	4	None
Gaia Research (2003)	Jervis Bay NR	360 (Ea), 72(Eb), 36(C)	4	None
Townley (2007)	Pacific City Estate, Jervis Bay NP	2750 (Ea), 126 (C)	5	White-footed Dunnart, Eastern Chestnut Mouse
Gaia Research (2008)	Jervis Bay NP and Woollamia NR	45 (Ea) + 240(C)	5	None
Lindenmayer *et al*. (2008).	Booderee NP, Jervis Bay	1913(Ea) 11568 (C) 11568 pit falls	7	White-footed Dunnart, Eastern Chestnut Mouse Eastern Pygmy Possum
Townley (2008)	Pacific City Estate, Jervis Bay NP	1860 (Ea)	7	Eastern Chestnut Mouse Eastern Pygmy Possum
Townley (2009)	Pacific City Estate, Jervis Bay NP	1800(Ea)	7	White-footed Dunnart, Eastern Chestnut Mouse
Gaia Research (2009)	Worrigee NR, Brundee Swamp NR and Saltwater Swamp NR	150(Ea) and 78(C)	5	None
Gaia Research (2011a)	Colymea SCA	300(Ea) + 60(C)	1	None
Gaia Research (2011b)	Jerrawangala NP and Parma Ck NR	540(Ea) + 106(C)	5	Eastern Pygmy Possum
Daly unpub. data 2011	Meroo National Park	120(Ea) + 24(C)	3	White-footed Dunnart
Daly unpub. data 2013	Corramy RP	150(Ea) + 30(C)	4	White-footed Dunnart

years (reasons unknown), a decline in the number of Swamp Rats and an increase in the population of Bush Rats as the vegetation senesced. I concur with Sutherland and Dickman (1999) that drawing conclusions on the response of these mammals to fire is complicated by different patterns in different habitats, or even within similar habitat types at different locations.

The trapping rate of 26% (range 14-39%) was considerably higher than that found by Townley (2007-9) (range of 6-9%) who trapped in similar vegetation types within one kilometre of my study site. Reasons that may explain the difference in capture rate may be disturbance (resulting in the presence of House Mouse), habitat diversity and the presence of loose rock in areas of my study site.

White-footed Dunnart

In the Shoalhaven local government area the White-footed Dunnart has been found in heathland and woodland on sandy substrates as well as tall open Spotted Gum *C. maculata* forest with a clay substrate and sparse ground cover. Locations where the species has been trapped include Booderee NP (King 1980, Lindenmayer *et al.* 2008), Bugong NP (Daly and Murphy 1996), Currambene State Forest (Braithwaite *et al.* 1988), Parma Creek (Barrer 1990), Murramarang NP (Atlas of Living Australia), Conjola NP (Daly *et al.* 1998), Vincentia (Daly 1994, Gaia Research 2001) Dolphin Point (BES 2006a), Meroo NP (Daly unpub. data) and Corramy Regional Park (Daly unpub. data). Several of the sites where the White-footed Dunnart was found had recently been burnt.

There is considerable confusion as to the identity of the White-footed Dunnart as the species is morphologically very similar to the Common Dunnart *S. murina* (Morton *et al.* 1979, Archer 1981). As the two species do not appear to be sympatric in southern NSW and Victoria (Morton *et al.* 1979) it is likely that only the White-footed Dunnart is present in the study area.

A White-footed Dunnart was trapped on the site in 1994 then five in 2000 (over the 10 day trapping session) and another in 2009 in an area recently burnt. No White-footed Dunnarts have been trapped since that time suggesting the species is either absent or persists in low densities in unburnt areas. This concurs with other results within the region (Lindenmayer *et al.* 2008, Braithwaite *et al.* 1988, Barrer 1990, Daly unpub. data).

One measure of a species population status (or trap shyness) is trap nights until first capture (Table 4). In this study only 55 trap nights were necessary to detect this species. However, this measure alone may give a misleading impression of the species status especially if trapping occurs in suitable habitat that has been recently burnt. In this study a number of animals were trapped in the first year over a 10 day period, but these data were not included in the analysis as the rest of the dataset were based on four nights trapping. Excluding the non-conforming data it took seven years and 1495 trap nights to capture the second specimen.

Fire is important for maintaining the native small ground-dwelling mammal species diversity in this region as plant succession post-fire provides an environment that these have co-evolved with. The failure to trap White-footed Dunnart in the period 2010-2014 may be due to the absence of fire, low density, trapping method, trap shyness and/or trap period or a combination of these factors.

Eastern Chestnut Mouse

Studies at Myall Lakes on the central coast of NSW found that the Eastern Chestnut Mouse was an early seral stage colonist post-wildfire in heath, peaking 18 months after wildfire (Fox 1982; Higgs and Fox 1993; Thompson and Fox 2003, Higgs and Fox 1993; Fox *et al.* 2003; Monamy and Fox 2010). Townley (2007, 2008 and 2009) found that the population in Jervis Bay NP was highly associated with Heath Banksia that had been burnt. Pereoglou *et al.* (2011) found the Eastern Chestnut Mouse selected refugia that included tall, dense vegetation.

In the current study a total of eight Eastern Chestnut Mouse were trapped on transects that supported woodland/heath and had loose rocks. These transects had not been burnt for 12-17 years, which is not in accord with the seral colonising behaviour recorded in other studies (Fox and McKay 1981). The only Eastern Chestnut Mouse captured during the surveys in an area recently burnt was at transect 1 during 2010, one year after the burn. An area of bush adjacent to transect four was cleared two to three years prior to the first capture suggesting that disturbance from clearing may have stimulated the species to colonise that site for a period.

Townley (2008 & 2009), who surveyed small mammals approximately one kilometre from the current survey site found Eastern Chestnut Mouse was the most abundant small mammal with 43 and 39 captures over 1860 trap nights. Lindenmayer *et al.* (2008) trapped 22 Eastern Chestnut Mouse over a broad area in Booderee NP over 17,440 Elliott trap nights.

These studies (Table 7) indicate that the Eastern Chestnut Mouse has a patchy distribution on the Bherwerre peninsula. This explains why the species was undetected in the region until hairs were found in a fox scat (Meek and Triggs 1977). The first live animal was caught in 2006 after 1065 trap nights during this study. No Eastern Chestnut Mouse have been reported elsewhere in the region and the Jervis Bay population appears to be isolated from those further north.

New-holland Mouse

Previous studies indicate that New-holland Mouse populations increase following fire (Posamentier and Recher 1974, Braithwaite and Gullan 1978, Fox and

Fox 1978, Fox and McKay 1981, Fox 1982). Elevated populations can be sustained for up to five years post wildfire (Fox 1982) or clearing (Kemper 1990) before declining (Posamentier and Recher 1974). The single female caught during the current survey (after 1825 trap nights) was beside an area that had recently been cleared as part of the development.

The southern limit of the New-holland Mouse in New South Wales is Bherwerre peninsula, Jervis Bay (Atlas of Living Australia accessed 5 Jan 2016). In this study the animal was found in a floristically diverse site (transect 4), which was dominated by depauperate Red Bloodwood, Heath-leaved Banksia, Dagger Hakea and Epacris-leaved Tea-tree.

Most small terrestrial mammal studies in the Jervis Bay area have failed to capture this species (Townley 2007, 2008, 2009, Lindenmayer *et al.* 2008, Douglas quoted in Posamentier and Recher 1974) indicating this species is regionally rare. In contrast this was the most abundant species trapped on the central coast of New South Wales (Kemper 1990) and was the third most abundant mammal at a site in the eastern Otways, Victoria (Wilson 1991).

Eastern Pygmy Possum

Within the Jervis Bay region the Eastern Pygmy Possum has been found in heathland and or Scribbly Gum-Red Bloodwood woodland. The species has been trapped in Jervis Bay NP (Townley 2008 and 2009) adjacent to the site and on the broader Bherwerre Peninsula (Lindenmayer *et al.* 2008). Harris *et al.* (2007) trapped three individuals, two in Elliott traps and one in a pitfall trap. The largest number caught in the region were in Booderee NP where Lindenmayer *et al.* (2008) caught 25 individuals over 19130 Elliott trap nights and 11568 pitfall nights.

In the Shoalhaven region Eastern Pygmy Possum has been found in Jerrawangala NP (Gaia Research 2011a), Morton NP near Tallowa Dam (Daly unpub. data) and north Nowra (BES 2006b, NGH environmental 2012). At most sites the vegetation is woodland that has a species diverse shrublayer of heathland species such as Grass Trees and Banksia (*B. serrata, B. ericifolia* and *B. spinulosa*). This is in accord with Van Dyke and Strahan (2008) who state the species feeds largely on nectar and pollen collected from banksias, eucalypts and bottlebrushes.

Harris *et al.* (2007) reviewed the number of Eastern Pygmy Possum detected in the Jervis Bay area. In Booderee NP the capture rate ranged between 0.12-0.14/100 trap nights. The current study had a capture rate of 0.03/100 trap nights, which was relatively low compared to other studies in the area.

The reasons for the low capture rate may partially be a result of the methods used in this survey. I set Elliott traps on the ground whereas Harris *et al.* (2007) set most traps in trees. Honey was used in the bait mix by Harris *et al.* (2007), whereas I did not have honey in the bait for ethical reasons (honey attracts ants increasing the chance of trapping Eastern Bristlebird and possible mortalities).

The species is generally trap shy being rarely caught in Elliott traps but the survey site had bedrock close to the surface and installing pit fall traps was not feasible. In one study (Bladon *et al.* 2002), capture rates in nest boxes were about 33 per 100 box checks per month. This equated to about 15-20 animals in a 4 ha area. To monitor Eastern Pygmy Possum it may be better to install nest boxes specifically designed for the species (Ashby unpub. data) than use Elliot traps.

Brown Antechinus

The Brown Antechinus was the second most abundant small mammal species with 3.7 captures per 100 trap nights. Trapping during the surveys was usually undertaken in September when juveniles are not independent and the population is at its minimum (Wood 1970). Significantly more Brown Antechinus were trapped at transects (5 and 6) that supported dense stands of Heath-leaved Banksia. This result was in accord with other studies that found this habitat supports high densities of this species (Dickman and Woodside 1983, Knight and Fox 2000).

Tasker and Dickman (2004) state that where vegetation cover is dense the presence of hollow logs is not crucial for Brown Antechinus. While the study site has dense vegetation cover it generally lacks fallen logs as trees do not attain a large stature. Antechinus must take refuge under rocks, in the few tree hollows or in dense vegetation. Transect five had the densest vegetation and the highest number of ground dwelling mammals. In the woodland transects released Antechinus were observed to take refuge in small hollows in depauperate Red Bloodwood. This concurs with previous observations that the species takes refuge in tree hollows (Dickman and Steeves 2004).

Prior to the 2009 burn Brown Antechinus were regularly trapped at transect 1. They were not retrapped at this site until four years post-burn supporting previous findings that this species prefers dense vegetation (Dickman and Woodside 1983, Knight and Fox 2000).

Swamp Rat

A number of studies have found that Swamp Rat have a preference for moist areas with a dense cover of low vegetation, especially where the monocots *Imperata cylindrica* and or *Lomandra longifolia* occur (Fox and McKay 1981, Fox 1984, Hearing and Fox 1995, Maitz and Dickman 2001, Tasker and Dickman 2004). In this survey significantly more Swamp Rats were trapped at those transects with a diversity of plant species and loose rock (transects 2 and 4). Higher

numbers were also trapped at a site with low diversity but very dense vegetation (transect 5). While this species is generally considered to prefer habitat in the later stages of post fire regeneration (Fox 1982, Higgins and Fox 1993, Fox *et al.* 2003, Kearney *et al.* 2007, Monamy and Fox 2010), it has been found to decline with increasing numbers of Bush Rats. The population within the study area declined over the last few years of the monitoring period.

No Swamp Rats were caught in the area burnt in 2009, albeit the species was only trapped on this transect once prior to the fire. It is suggested that the main driver of the population decline may have been the progressive drying of the site.

Bush Rat

The Bush Rat was the most abundant mammal with a trap rate of 7.38 captures per 100 trap nights. The average number of Bush Rats caught in Elliott traps between 2003-14 ranged from 4-17 (Figure 5). Total (Elliott and cage traps) Bush Rat captures varied significantly over the entire monitoring period. A number of studies have found that Bush Rats have a preference for areas with a dense cover of native vegetation (Lindenmayer *et al.* 2008, Dickman and Woodside 1983, Maitz and Dickman 2001, Tasker and Dickman 2004). The Bush Rat was trapped on all transects but only four captures were made at the transect regenerating post 2009 burn. Significantly more Bush Rats were trapped on the transect (5) that had the densest vegetation cover (Table 1).

Long-nosed Bandicoot

Long-nosed Bandicoot were trapped across the study area in all vegetation communities. The dependence of Long-nosed Bandicoot on dense undergrowth for diurnal nesting and temporary nocturnal sheltering; and open areas for foraging (Chambers and Dickman 2002, Hughes and Banks 2010) indicates that the mosaic of habitat on the course created by the retention of dense heathland and provision of open grassed areas may have benefited this species. Studies in nearby Booderee NP found that Long-nosed Bandicoot home-range size was positively related to the bodyweight of individuals, with males having a home range of about 4 ha and females about 1.9 ha (MacGregor *et al.* 2013). Hence animals trapped in the study would have foraged over most of the site.

House Mouse

The number of House Mice varied significantly over the survey with a peak in 2005 and then a decline with none trapped in the last two years. The distribution and density of the House Mouse was significantly associated with disturbance resulting from clearing and possibly fire as the species was more abundant on transects 2, 3 and 4. No House Mice were trapped on transect 6, which had the least disturbance. Since 2011, when clearing ceased, the species declined.

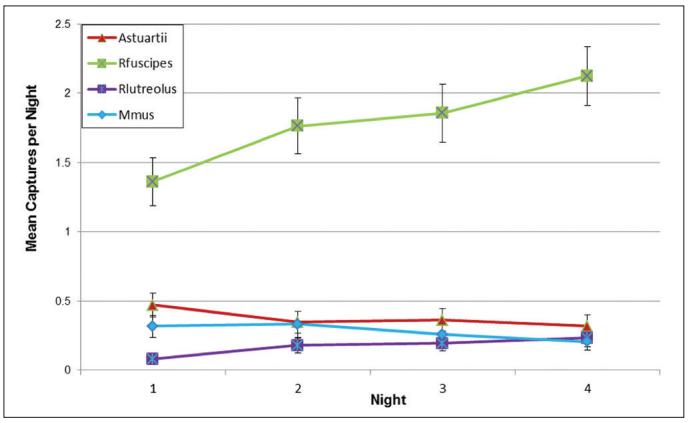

Figure 5. Mean number of common mammal species caught in Elliott traps per night for the period 2003-2014

Note: Error bars denote one standard deviation of the mean.

There was a post-fire pulse in the population at transect one, a trend which has been observed in other studies (Newsome *et al.* 1975; Fox 1982; Kemper 1990; Catling 1991, Sutherland and Dickman 1999). In the current study the House Mouse population peaked eleven years post-fire across all sites. Disturbance from clearing is considered to have been the driver for this population increase.

Birds

Eastern Bristlebird

The Eastern Bristlebird is listed as endangered under state and commonwealth legislation. The population at Vincentia is part of the central section of its distribution (OEH 2012). This central population is fragmented into the subpopulations at Budderoo/ Barren Grounds NP (est. 1000 birds), Woronora (est. 15 birds), Cambewarra Range (est. 20 birds), Morton NP (unknown) and Jervis Bay (est. 1100 birds including the translocated population on Beecroft peninsula) (G. Daly pers. obs; Baker *et al.* 2012, OEH 2012).

The Eastern Bristlebird at the survey site is part of the Jervis Bay subpopulation that extends from Booderee NP, through a portion of Jervis Bay NP west to Tomerong (G. Daly unpub. data). However, even within this area land clearing associated with urban expansion has further fragmented the habitat.

The aural transect surveys gave an estimate of the number of Eastern Bristlebird on and adjacent to the site. However, the capture of birds in traps revealed that there were additional animals (possibly juveniles?) that were not calling during aural surveys. Elsewhere Eastern Bristlebird have rarely been captured in mammal traps (J. Baker pers. comm.). The site has the highest number of birds trapped in any area (0.75 birds per 100 trap days) indicating a high population of this species. Eastern Bristlebird mostly eat ants and

beetles (Gibson and Baker 2004). Ants were observed eating the bait and they may have enticed birds into the traps to feed on the ants them. Presumably the application of fertiliser had attracted insects to that area of the golf course.

Ground Parrot

The Ground Parrot is listed as endangered in NSW, where the population was estimated at c. 2000 birds occurring at Barren Ground Nature Reserve / Budderoo National Park (1000), Jervis Bay (550), Nadgee Nature Reserve (300) and Ben Boyd National Park (100) (Baker 1997, NPWS 2000). The animals detected during this survey are part of the Jervis Bay population, but based on known dispersal abilities (Higgins 1999) probably disperse elsewhere in the region such as Morton NP and Barren Grounds NP.

The species was highly associated with heath/sedgelands with foliage cover greater than 60%, which is consistent with other work (http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=734; Meredith 1984). The failure to detect birds for the last decade may relate to the vegetation maturing in the absence of fire as two pairs have been regularly detected in the adjacent area of Jervis Bay NP burnt in 2005 (C. Grounds pers. comm.).

Acknowledgements

I thank R. Rudd and M. Smith for help with the surveys, G. Chapman, C. Grounds and the late D. Wright for data on the rare birds and G. Hoye for statistical analyses and review of the manuscript. The manuscript was improved by constructive comments from two anonymous reviewers. Work was conducted under Scientific Licence S10470.

References

AES 1995. Draft Strategic Flora and fauna study Heritage Estates City of Shoalhaven. Report prepared for Shoalhaven City Council.

Andrews, N. 1994. Flora and fauna assessment Heritage Estate Jervis Bay. Report to Hassell Planning Consultants.

Archer, M. 1981. Results of the Archbold expeditions. No. 104. Systematic revision of the marsupial dasyurid genus *Sminthopsis* Thomas. *Bull. Am. Mus. Nat. Hist.* **168:** 94-110.

Baker, J. 1997. Ground Parrot Recovery Plan 1997-2002. New South Wales National Parks and Wildlife Service, Sydney

Baker J. 1998. Ecotones and fire and the conservation of the endangered eastern bristlebird. PhD thesis, University of Wollongong.

Baker, J., Bain, D., Clarke, J. & French, K. 2012. Translocation of the Eastern Bristlebird 2: applying principles to two case studies. *Ecological Management and Restoration* **13**: 159-65. http://dx.doi.org/10.1111/j.1442-8903.2012.00640.x

Barrer, P. 1990. Report on a reconnaissance survey of native flora and fauna in the vicinity of Hellhole, near Nowra. Report prepared for P. D. James and Company.

Bladon, R. V., Dickman, C. R. and Hume, D. I 2002. Effects of habitat fragmentation on the demography, movements and social organisation of the eastern pygmy-possum (Cercartetus nanus) in northern New South Wales. *Wildlife Research.* **29**: 105-116. doi:10.1071/WR01024.

Braithwaite, R. W. and Gullan, P. K. 1978. Habitat selection by small mammals in a Victorian heathland. *Australian Journal of Ecology.* **3:** 109-127. http://dx.doi.org/10.1111/j.1442-9993.1978.tb00857.x

Braithwaite, L. W., Austin, M. P., Margules, C. R., Catling, P. C. and Bedward, M. 1988. Jervis Bay Flora and Fauna. Survey and Assessment of specific site for the Jervis Bay Armament Depot Environmental Impact Assessment. CSIRO Division of Wildlife Biology.

Bushfire and Environment Services. 2006a. Flora and fauna assessment. Proposed mixed use, residential, Commercial and recreational development (Stages 2, 3 and 5). Lot 1 DP 1045990 Princes Highway Dolphin Point Shoalhaven. Report prepared for Elderslie Property Investments Pty Ltd.

Bushfire and Environment Services. 2006b. Flora and fauna assessment. Proposed rural subdivision. 1433 DP 1008407 Tallimba and Counsel Rds, Bangalee Shoalhaven. Report prepared for Southbank Land Pty Ltd and Huntingdale Developments Pty Ltd.

Capararo, S. M. and Murphy, M. J. 1996. Fox control at Jervis Bay, New South Wales. Monitoring of native fauna populations. Report prepared for the NSW NPWS.

Catling, P. C. 1991. Ecological effects of prescribed burning practices on the mammals of south-eastern Australia. Pp 353-65. In *Conservation of Australia's Forest Fauna* (ed Lunney, D.). Surrey Beatty and Sons, Sydney.

Caughley, J. 1993. A wildlife survey of Bherwerre isthmus. Report prepared for Australian Nature Conservation Agency.

Chambers, L. K., and Dickman, C. R. 2002. Habitat selection of the long-nosed bandicoot *Perameles nasuta* (Mammalia: Peramelidae), in a patchy urban environment. *Austral Ecology* **27**, 334–342. http://dx.doi.org/10.1046/j.1442-9993.2002.t01-1-01185.x

Coyne, P. C., Hinchey, M. D. and Jenkins, R. W. G. 1979. Beecroft Peninsula. A survey of the natural resources of

Department of Defence controlled land. Report prepared for ANCA.

Daly, G. 1994. Fauna assessment Lively Street, Vincentia. City of Shoalhaven New South Wales. Report prepared for Queanbeyan Investments Pty Ltd.

Daly, G. and Leonard G. 1996. Fauna and flora of 'Long Bow Point', Culburra Shoalhaven City. Report prepared for Reality Realisations Pty Ltd by Gaia Research Pty Ltd.

Daly, G. and Murphy, M. 1996. Fauna audit: northern Shoalhaven. Report prepared for the Lower Shoalhaven Catchment Management Committee.

Daly, G.; Gosper, C. and German, P. 1998. Fauna assessment. Cudmirrah and Conjola region, Shoalhaven City. Report prepared for the NSW NPWS by Gaia Research Pty Ltd.

Dickman, C. R. and Steeves, T. E., 2004. Use of habitat by mammals in eastern Australian forests: are common species important for forest management? Pp. 761-73 in Conservation of Australia's Forest Fauna (2nd edition), edited by D. Lunney. Royal Zoological Society of NSW, Mosman. http://dx.doi.org/10.7882/FS.2004.046

Dickman, C. R. and Woodside, D. P. 1983. A test of a competition model with reference to three species of small mammals in south-eastern Australia. *Oecologia* **63**: 127-134. http://dx.doi.org/10.1007/BF00379332

Harden, G. (ed). 1990-3. *Flora of New South Wales. Volumes 1 to 4.* Royal Botanic Gardens/University of NSW Press, Sydney.

Higgins, P.J. (ed.) (1999). Handbook of Australian, New Zealand and Antarctic Birds. Volume Four - Parrots to Dollarbird. Melbourne: Oxford University Press.

Higgs, P., and Fox, B. J. 1993. Interspecific competition: a mechanism for rodent succession after fire in wet heathland. *Australian Journal of Ecology* **18:** 193–201. doi:10.1111/j.1442-9993.1993.tb00443.x

Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. *Annu. Rev. Ecol. Evol. Syst.* **34:** 487–515. http://dx.doi.org/10.1146/annurev.ecolsys.34.011802.132419

Fox, B. J. 1982. Fire and mammalian secondary succession in an Australian coastal heath. *Ecology* **63**: 1332–1341. http://dx.doi.org/10.2307/1938861

Fox, B. J. 1984. Small scale patchiness and its influence on our perception of animal species' habitat requirements. Pp.162-178 in Survey Methods for Nature Conservation, edited by K. Myers, C. R. Margules and I. Musto. CSIRO, Canberra.

Fox, B.J. & Fox, M.D. 1978. Recolonisation of coastal heath by *Pseudomys novaehollandiae* (Muridae) following sand mining. *Australian Journal of Ecology*. **3**: 447-465.

Fox, B. J. and McKay, G. M. 1981. Small mammal responses to pyric successional changes in eucalypt forest. *Australian Journal of Ecology* **6**: 29-41.

Fox, B. J., Taylor, J. E., and Thompson, P. T. 2003. Experimental manipulation of habitat structure: a retrogression of the small mammal succession. *Journal of Animal Ecology* **72:** 927–940. doi:10.1046/ j.1365-2656.2003.00765.x

Gaia Research 1999. Survey of the ground and arboreal mammals at Jervis Bay, Nowra. Report prepared for the NSW NPWS, Nowra.

Gaia Research 2001. Species Impact Statement. Extension of Vincentia Golf Course, Vincentia. Report prepared for Vincentia Golf Club.

Gaia Research 2003-12. Monitoring fauna and flora. Extensions to existing golf course Vincentia, Shoalhaven City. Report prepared for Vincentia Golf Club.

Gaia Research 2003. Survey of ground and arboreal mammals at Jervis Bay, National Park. Report prepared for the NSW NPWS.

Gaia Research 2008. Targeted fauna surveys and monitoring mammals Jervis Bay National Park and Woollamia Nature Reserve. Nowra. Report prepared for the Department of Environment and Climate Change NSW, Parks and Wildlife Group, South Coast Region, Nowra.

Gaia Research 2009. Targeted fauna surveys of Worrigee Nature Reserve, Brundee Swamp Nature Reserve and Saltwater Swamp Nature Reserve, Nowra. Report prepared for the Department of Environment and Climate Change NSW, Parks and Wildlife Group, South Coast Region, Nowra.

Gaia Research 2011a. Fauna surveys at Colymea State Conservation Area. Report prepared for the NSW National Parks and Wildlife Service, Office of Environment and Heritage, Nowra. Nowra.

Gaia Research 2011b. Fauna surveys at Jerrawangala National Park and Parma Creek Nature Reserve. Report prepared for the NSW National Parks and Wildlife Service, Office of Environment and Heritage, Nowra.

Gibson, L. and Baker, J. 2004. Diet of the eastern bristlebird *Dasyornis brachypterus* in New South Wales. *Corella* **28:** 79-81.

Haering, R. and Fox, B. J., 1995. Habitat utilization patterns of sympatric populations of *Pseudomys gracilicaudatus* and *Rattus lutreolus* in coastal heathland: a multivariate analysis. *Australian Journal of Ecology* **20:** 427-441. http://dx.doi.org/10.1111/j.1442-9993.1995.tb00559.x

Harris, J.M., Goldingay, R. L., Broome, L., Craven, P. Maloney, K. S. 2007. Aspects of the ecology of the eastern pygmy possum *Cercartetus nanus* at Jervis Bay, New South Wales. *Australian Mammalogy* **29**: 39-46. http://dx.doi.org/10.1071/AM07004

Higgs, P. and Fox, B. J. 1993. Interspecific competition: a mechanism for rodent succession after fire. *Australian Journal of Ecology* **18:** 193-201.

Hughes, N. K., and Banks, P. B. 2010. Heading for greener pastures? Defining the foraging preferences of urban long-nosed bandicoots. *Australian Journal of Zoology* **58**, 341–349. http://dx.doi.org/10.1071/ZO10051

Kingsford, R.T., Watson, J.E.M., Lundquist, C.J., Venter, O., Hughes, L., Johnston, E.L., Atherton, J., Gawel, M., Keith, D.A., Mackey, B.G., Morley, C., Possingham, H.P.,

Raynor, B., Recher, H.F., Wilson, K.A., 2009. Major conservation policy issues for biodiversity in oceania. *Conserv. Biol.* **23:** 834–840. http://dx.doi.org/10.1111/j.1523-1739.2009.01287.x

Kemper, C. M. 1990. Small mammals and habitat disturbance in open forest of coastal New South Wales. I. Population parameters. *Australian Wildlife Research* **17**: 195–206. http://dx.doi.org/10.1071/WR9900195

Kevin Mills and Associated Pty Ltd 1998a. Species Impact Statement Stage 1 Bay and Basin Leisure Centre City of Shoalhaven. Report prepared for Shoalhaven City Council.

Kevin Mills and Associated Pty Ltd 1998b. Supplementary Information Species Impact Statement Stage 1 Bay and Basin Leisure Centre City of Shoalhaven. Report prepared for Shoalhaven City Council.

King, D. H. 1980. Extension of the New South Wales range of the white-footed dunnart, *(Sminthopsis leucopus* Gray*)*. *Victorian Naturalist* **97:** 263-65.

Kearney, N., Handasyde, K., Ward, S., and Kearney, M. 2007. Fine-scale microhabitat selection for dense vegetation in a heathland rodent, *Rattus lutreolus*: insights from intraspecific and temporal patterns. *Austral Ecology* **32:** 315–325. doi:10.1111/j.1442-9993.2007.01697.x

Knight E.H. and Fox B.J. 2000. Does habitat structure mediate the effects of forest fragmentation and human-induced disturbance on the abundance of *Antechinus stuartii*? *Australian Journal of Zoology* **48**: 577-595. http://dx.doi.org/10.1071/ZO00018

Lindenmayer, D.B., and Fischer, J., 2006. *Habitat Fragmentation and Landscape Change.* Island Press, Washington.

Lindenmayer, D. B., MacGregor, C., Welsh, A., Donnelly, C., Crane, M., Michael, D., Montague-Drake, R., Cunningham, R. B., Brown, D., Fortescue, M., Dexter, N., Hudson, M., and Gill, A. M. 2008. Contrasting mammal responses to vegetation type and fire. *Wildlife Research* **35:** 395–408. http://dx.doi.org/10.1071/WR07156

Macgregor, C., Wood, J. T., Dexter, N. and Lindenmayer, D. B. 2013. Home range size and use by the long-nosed bandicoot (*Perameles nasuta*) following fire. *Australian Mammalogy* **35**: 206–216. http://dx.doi.org/10.1071/AM12032

Maitz, W. E. and Dickman, C.R. 2001. Competition and habitat use in native Australian *Rattus*: is competition intense, or important? *Oecologia* **128**: 526-538. http://dx.doi.org/10.1007/s004420100689

Meek, P. D. and Triggs, B. 1997. Extension to the range of the Eastern Chestnut Mouse, *Pseudomys gracilicaudatus,* to Jervis Bay, New South Wales. *Australian Mammalogy* **20:**123-25.

Meredith, C.W. 1984. The Ground Parrot *Pezoporus wallicus* Kerr. RAOU Report 10.

Monamy V. and Fox B.J., 2010. Responses of two species of heathland rodent to habitat manipulation: vegetation density thresholds and the habitat accommodation model. *Austral Ecology* **35**: 334-347. http://dx.doi.org/10.1111/j.1442-9993.2009.02042.x

Morton, S. R. Wainer, J. W and Thwaites T. P. 1979. Distributions and habitats of *Sminthopsis leucopus* and *Sminthopsis murina* (Marsupialia: Dasyuridae) in southeastern Australia. *Australian Mammalogy* **3:** 19-30.

Murphy, M. J. 1998. Mammal survey of Seven Mile Beach National Park and Comerong Island Nature Reserve on the south coast of New South Wales. *Australian Zoologist* **30:** 419-425. http://dx.doi.org/10.7882/AZ.1998.008

National Parks and Wildlife Service 1999. NSW Comprehensive Regional Assessments. Vertebrate Fauna Surveys Field Survey Methods. RACAC and DUAP.

National Parks and Wildlife Service 2000. Draft Recovery Plan for the Ground Parrot *(Pezoporus wallicus)*. NSW NPWS Threatened Species Unit Southern Zone, Queanbeyan.

Newsome, A. E., McIlroy, J. C., and Catling, P. C. 1975. The effects of extensive wildfire on populations of twenty ground vertebrates in southeast Australia. Proceedings of the *Ecological Society of Australia* **9**, 107–123.

NGH environmental 2012. Fauna surveys. Local reference site surveys for threatened species in the north Nowra area. Report prepared for Southbank Land Pty Ltd and Huntingdale Developments Pty Ltd.

OEH 2012. National Recovery Plan for Eastern Bristlebird *Dasyornis brachypterus*. Office of Environment and Heritage, Department of Premier and Cabinet (NSW), Sydney.

OEH 2013. Biometric vegetation types and endangered ecological communities of the Shoalhaven, Eurobodalla and Bega Valley local government areas. Technical Report. NSW Office of Environment and Heritage, Queanbeyan.

Pereoglou, F, MacGregor, C, Banks, S., Ford F.D., Wood J.T. and Lindenmayer D.B. 2011. Refuge site selection by the eastern chestnut mouse in recently burnt heath. *Wildlife Research* **38:** 290-298. http://dx.doi.org/10.1071/WR11007

Posamentier, H. G., and H. F. Recher. 1974. Status of *Pseudomys novaehollandiae*. *Australian Zoologist* **18**:66-71.

Sutherland, E. F., and Dickman, C. R. 1999. Mechanisms of recovery after fire by rodents in the Australian environment: a review. *Wildlife Research* **26**: 405–419. http://dx.doi.org/10.1071/WR97045

Tasker, E. M. and Dickman, C. R. 2004. Small mammal community composition in relation to cattle grazing and associated burning in eucalypt forests of the Northern Tablelands of New South Wales. Pp 721 - 740 in the Conservation of Australia's Forest Fauna (second edition) 2004, edited by Daniel Lunney. Royal Zoological Society of New South Wales, Mosman, NSW, Australia. http://dx.doi.org/10.7882/FS.2004.043

Thompson, P. & Fox, B.J. 1993. Asymmetric competition in Australian heathland rodents: a reciprocal removal experiment demonstrating the influence of size-class structure. *Oikos*. **67**: 264–278. http://dx.doi.org/10.2307/3545471

Townley, S. 2007. Targeted survey for the eastern chestnut mouse *Pseudomys gracilicaudatus,* New Holland Mouse *Pseudomys novaehollandiae,* Eastern Pygmy Possum *Cercartetus nanus and* Long-nosed bandicoot *Perameles nasuta* on the Pacific city estate lands, Jervis Bay National Park. Report prepared for DECC, Jervis Bay area.

Townley, S. 2008. Monitoring of *Pseudomys gracilicaudatus* (Eastern Chestnut Mouse) in Jervis Bay National Park. Report prepared for NSW NPWS, Nowra.

Townley, S. 2009. Monitoring of *Pseudomys gracilicaudatus* (Eastern Chestnut Mouse) in Jervis Bay National Park. Report prepared for DECC, Nowra.

Van Dyck, S, and Strahan, R. 2008. *The Mammals of Australia.* Third edition. Reed New Holland, Sydney.

Wilson, B. A. 1991. The ecology of *Pseudomys novaehollandiae* (Waterhouse, 1843) in eastern Otways Ranges, Victoria. *Wildl. Res.* **18:** 233-47.

Wood, D. H. 1970. An ecological study of *Antechinus stuartii* (Marsupialia) in a south-eastern Queensland rain forest. *Australian Journal of Zoology* **18:** 185-208.

APPENDIX 1

Vegetation cover scores over the survey period

Note: cover shows the percentage range from 2003 to 2014.

Site 1.

Ht range	Cover	Species 1	% cover	Species 2	% cover	Species 3	% cover
3 to 5m	25-30%	*Corymbia gummifera*	2	*Leptospermum trinervium*	1		
1 to 3m	70-50%	*Banksia ericifolia*	2	*Leptospermum rotundifolium*	2	*Hakea teretifolia*	1
<1m	80-55%	*Restio fastigatus*	1	*Lepidosperma filiforme*	1	*Lepyrodia scarious*	1

Site 2.

Ht range	Cover	Species 1	% cover	Species 2	% cover	Species 3	% cover
3 to 10m	25-30%	*Eucalyptus sclerophylla*	2	*Corymbia gummifera*	2	*Banksia serrata*	1
1 to 3m	75-40%	*Banksia ericifolia*	2	*Hakea teretifolia*	2	*Petrophile sessilis*	1
< 1m	50-20%	*Restio fastigatus*	1	*Lepidosperma filiforme*	1	*Leptocarpus tenax*	1

Site 3.

Ht range	Cover	Species 1	% cover	Species 2	% cover	Species 3	% cover
3 to 8m	<10-20%	*Eucalyptus sieberi*	1	*Allocasuarina distyla*	1		
1 to 3m	85-70%	*Banksia ericifolia*	2	*Leptospermum rotundifolium*	1	*Casuarina distyla*	1
<1m	70-60%	*Restio fastigatus*	2	*Lepidosperma concavum*	1	*Xanthorrhoea resinifera*	2

Site 4.

Ht range	Cover	Species 1	% cover	Species 2	% cover	Species 3	% cover
3 to 8m		No species					
1m to 2.m	70-80%	*Banksia ericifolia*	2	*Hakea teretifolia*	2	*Darwinia leptanthera*	1
< 1m	90-70%	*Restio fastigata*	2	*Leptocarpus tenax*	1	*Lepidosperma filiforme*	1

Site 5.

Ht range	Cover	Species 1	% cover	Species 2	% cover	Species 3	% cover
3 to 8m		No species					
1 to 3m	95-95%	*Banksia ericifolia*	4	*Hakea teretifolia*	1	*Allocasuarina distyla*	2
<1m	50-50%	*Restio fastigatus*	2	*Lepidosperma urophorum*	2	*Xanthorrhoea* sp.	2

Site 6.

Ht range	Cover	Species 1	% cover	Species 2	% cover	Species 3	% cover
6 to 10m	50-50%	*Eucalyptus sieberi*	2	*Corymbia gummifera*	2	*Banksia serrata*	1
2 to 6m	40-10%	*Banksia ericifolia*	1	*Banksia oblongifolia*	1		
< 2m	70-50%	*Lepidosperma viscidum*	2	*Caustis pentandra*	2	*Xanthorrhoea sp.*	2

Cover Abundance Scale for individual species

(Modified Braun-Blanquet)

1 – few individuals, 2 – many individuals, 3 – 6% - <25% cover, 4 – 26% - <50% cover, 5 – 51% - < 75% cover, 6 – 76% – 100% cover

APPENDIX 2

The threatened Eastern Chestnut Mouse *Pseudomys gracilicaudatus* trapped at Vincentia. This was the first live specimen to be caught on the south coast of NSW. Photo, G. Daly

The first Eastern Chestnut Mouse *Pseudomys gracilicaudatus* trapped on the south coast of NSW. Photo P. Craven

The threatened Eastern Pygmy Possum *Cercartetus nanus* was only caught once during the survey. Photo G. Daly

APPENDIX 2

Nearly all Brown Antechinus *A. stuartii* had pouched young. Photo G. Daly

The threatened White-footed Dunnart *Sminthopsis leucopus* was caught in an area that had been recently burnt. Photo, G. Daly

The southern limit of the New-holland Mouse *Pseudomys novaehollandiae* is Bherwerre peninsula, Jervis Bay. Photo, G. Daly

APPENDIX 2

The number of Swamp Rat *Rattus lutreolus* declined during the survey, possibly due to the site drying out. Photo, G. Daly

The House Mouse *Mus musculus* was trapped in high disturbed areas but was absent t in the last two years of the survey. Photo, G. Daly

The survey area at Vincentia supported a high population of the endangered Eastern Bristlebird *Dasyornis brachypterus*, with animals being trapped in cage and Elliott traps. Photo, G. Daly